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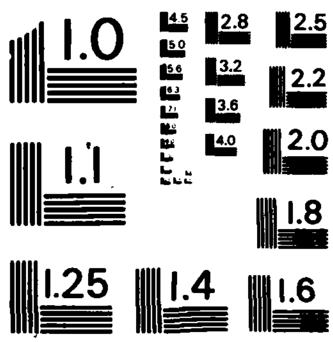
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NAVY EXPERIMENTAL DIVING UNIT
REPORT NO. 4-86

MANNED EVALUATION OF THE EX 15 MOD 1 UBA CARBON DIOXIDE ABSORBENT CANISTER

By

John L. Zumrick, CDR, MC, USN

NAVY EXPERIMENTAL DIVING UNIT

(6)

DEPARTMENT OF THE NAVY
NAVY EXPERIMENTAL DIVING UNIT
PANAMA CITY, FLORIDA 32407

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CANISTER DURATION
UBA
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Manned canister duration studies using the EX 15 Mod 1 UBA were conducted at 3 different exercise levels; rest, 50 watts intermittent work and 100 watts intermittent work. Studies were conducted at a depth of 66 FSW using a breathing mixture of 0.7 ATA in nitrogen. Conclusions from this study were: (1) The recommended EX 15 Mod 1 canister duration for most diving operations is 280 minutes independent of water temperature; (2) The recommended EX 15 Mod 1 canister duration for divers in a resting scenario,

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such as riding in an SDV, is 480 minutes independent of water temperature; (2) Canister duration was observed to have an inverse relationship to diver oxygen consumption, with the decrease in canister duration proportional to the increase in oxygen consumption.

ABSTRACT

Manned canister duration studies using the EX 15 Mod 1 UBA were conducted at 3 different exercise levels; rest, 50 watts intermittent work and 100 watts intermittent work. Studies were conducted at a depth of 66 FSw using a breathing mixture of 0.7 ATA in nitrogen. Conclusions from this study were: (1) The recommended EX 15 Mod 1 canister duration for most diving operations is 280 minutes independent of water temperature; (2) The recommended EX 15 Mod 1 canister duration for divers in a resting scenario, such as riding in an SDV, is 480 minutes independent of water temperature. Canister duration was observed to have an inverse relationship to diver oxygen consumption, with the decrease in canister duration proportional to the increase in oxygen consumption.

KEY WORDS:
EX 15 Mod 1
Canister Duration
UBA

INTRODUCTION

The EX 15 Mod 1 is a closed-circuit Underwater Breathing Apparatus (UBA) which uses an electronic control assembly to provide the diver with a mixed-gas breathing mixture consisting of 0.7 atmospheres absolute (ATA) partial pressure of oxygen (O_2) with the balance of the breathing mix composed of nitrogen (N_2). A complete description of the technical aspects of the EX 15 Mod 1 may be found in the EX 15 Operation and Maintenance Manual[1].

The desired operating duration for the EX 15 Mod 1 is 6 hours. The limiting factor on the maximum operating duration at present is the carbon dioxide (CO_2) absorbent canister. The EX 15 O&M Manual states that the canister life for the EX 15 Mod 0 is 160 minutes in 40°F water and 360 minutes in 70°F water[1]. These figures were based on early testing at NEDU[2] which did not include manned testing of the UBA. Subsequent manned testing of the EX 15 Mod 0[3] demonstrated that the canister could support a working diver for 117 minutes. Testing was done in both 35°F and 55°F water with essentially identical results. Because this canister life was far less than expected and because the EX 15 Mod 0 will be used primarily for Swimmer Delivery Vehicle (SDV) operations in which the diver performs only minimal physical work, the rig was tested again in a "mostly resting" scenario[4]. This scenario combined long periods of minimal exertion with brief increases in the activity level as might be encountered in SDV operations. When tested under these conditions in 55°F water, the canister duration was found to be 321 minutes, an increase of 175% over the working scenario.

Because of the failure of the EX 15 Mod 0 canister to meet the required 6 hour canister life, the UBA was reconfigured and designated the EX 15 Mod 1, incorporating the larger, better insulated MK 16 canister. Several other modifications were made as well[5].

This report describes the studies done to determine the CO_2 absorbent canister life of the EX 15 Mod 1 at 3 different exercise levels: Resting, 50 watts intermittent work, and 100 watts intermittent work. These different exercise levels were studied in order to observe the effect of various work rates on canister life.

METHODS

All divers were military divers who had been thoroughly trained in the use of the EX 15 Mod 1. Ten divers participated in the study: 9 male and 1 female. Their diver numbers, ages, heights, and weights are shown in Table 1.

These studies were conducted as part of a 60 FSW air saturation dive. All dives were conducted in the wet chamber of the NEDU Ocean Simulation Facility (OSF) hyperbaric complex with the diver depth (center chest) in the water

TABLE 1

DIVER CHARACTERISTICS

DIVER #	AGE (yrs)	HEIGHT (inches)	WEIGHT (pounds)
1	30	68	157
2	24	72	175
3	34	74	214
4	29	75	192
5	32	73	201
6	29	73	160
7*	30	62	126
8	26	70	157
9	31	72	175
10	27	67	156

* Female Diver

column being approximately 6 FSW for a net depth of 66 FSW. Water temperature was maintained at 55°F (12.8°C) ± 1°F throughout the study. Four studies were conducted simultaneously using four diver subjects each exercising on a similar underwater pedal mode ergometer[6].

For these studies, the usually horizontal ergometers were tilted upward to an angle of approximately 20° above the horizontal, so that the divers' head was slightly higher than his feet. This was done to reduce the increased inspiratory breathing resistance of the EX 15 Mod 1 which results when the diver's lungs are lower in the water column than the breathing bag.

Each diver wore one of three dry suit combinations for thermal protection: (1) The Passive Diver Thermal Protection Systems (PDTPS), consisting of an outer dry suit made of crushed foam neoprene (with gloves), full long john cotton underwear, wool socks, M400 Thinsulate thermal undergarment with socks and glove liners, and midline weights adjusted to diver preferences; (2) A Polyurethane coated nylon outer garment manufactured by Imperial Manufacturing Co., Inc., 32 oz. polypropylene undergarment, foam neoprene mitts and hood, and mid-line weights; or (3) The same Imperial Polyurethane coated outergarment but using M400 Thinsulate thermal undergarments. All divers also wore urine collection devices.

Prior to each dive day, four primary EX 15 Mod 1 UBAs plus one spare rig were set up on the surface and locked down to the divers. Rigs 1 and 2 were set up to maintain a partial pressure 0.85 ATA as part of feasibility study to determine whether the rigs would reliably control O_2 at this set point. Rigs 3 and 4 and the spare rig were set to control at the usual EX 15 oxygen partial pressure of 0.7 ± 0.05 ATA. Canisters were freshly packed and weighed prior to each dive using the same lot number of HP Sodasorb. A sample of HP Sodasorb from each bucket was obtained and placed in a sealed and labeled plastic bag for later analysis if needed. The diluent gas used in the study was air which was supplied to each diver's UBA via an umbilical. Spare batteries and oxygen bottles were kept in the trunk. If a diver needed to change his oxygen bottle or battery during the study, the change was made in the dry chamber during a rest period. The divers were instructed not to discontinue breathing from the UBA unless absolutely necessary and then for the minimum time possible.

Oxygen bottle pressure was measured with a Validyne DP 15, 3200 psi transducer connected to the EX 15 Mod 1 oxygen pressure gauge line. This transducer and its associated Validyne CD 19 signal conditioner were calibrated prior to and after each study from 0-2500 psig using a Mensor 11600 digital pressure gauge (2500 psig ± 0.04%). The linear regression of Validyne voltage versus digital pressure gauge reading was calculated by an HP 1000 computer. During the study the Validyne output voltage was sampled each minute and converted to pounds per square inch by the computer. After completing each study, a plot of oxygen bottle pressure versus time was made, and the oxygen consumption calculated, as will be discussed later.

Canister effluent CO_2 and O_2 gas samples were obtained by small diameter (.032 in i.d.) capillary sample lines with a sampling rate of 400 cc/min (STPD). The gas samples passed via a through-and-through chamber penetrator and continued unbroken to either a Perkin Elmer MGA 1100 or a Chemetron Model 7401 mass spectrometer. An accuracy of ± 0.01% was obtained by frequent calibrations during the experiment.

Rectal temperature was monitored using a YSI 700 series rectal probe. The signal was carried from the diver to a chamber electrical penetrator by a waterproofed umbilical, to a specially designed thermistor signal conditioner, and then to the HP 1000 computer by the MAC signal distributor.

All four divers dressed in one of the three prescribed thermal garment combinations for the dive in the dry chambers of the OSF complex. When fully dressed, they proceeded to the trunk where the UBA was donned and the instrumentation umbilical and diluent supply umbilicals were connected. When all equipment and instrumentation was ready, the diver entered the water. The diver remained at the foot of the ladder until all 4 divers had entered the water at which time they began breathing from the EX 15 Mod 1 and proceeded to their assigned bicycle ergometer. Divers were directed to request a replacement diver if they became fatigued or cold and the study was continued with the second diver using the same UBA and canister. For the resting protocols (described below), very long dive times were anticipated and a planned diver change as accomplished for all 4 divers at approximately 6 hours into the dive.

Three exercise protocols were used: Rest, 50 watts, and 100 watts. For the 50 and 100 watt protocols, the divers exercised in alternating periods of 4 minutes rest and 6 minutes of work. The initial 4 minutes of the study was a rest period to give the divers a chance to situate themselves at the ergometer. The work periods consisted of 6 minutes of pedalling the bicycle at 55-60 rpm at a resistance setting designed to provide the appropriate work rate. Since the bikes were calibrated in a dry environment, the added factors of submersion and use of a dry suit result in a diver work rate 25-50 watts above the ergometer setting.

For the resting protocol, the divers were resting for the entire study except for 2 six minute work periods at the beginning of the study and a single six minute work period at the start of each subsequent hour. In the event that canister breakthrough had not occurred by 11 hours and 30 minutes, the divers were directed to complete 3 work cycles before the dive was stopped at a maximum time of 12 hours.

Dives were terminated when the canister effluent CO_2 rose above 2.0% SEV continuously for 2 minutes, canister breakthrough was not achieved within 12 hours, or on demand of the diver-subjects.

RESULTS

Oxygen Consumption

The formula below was used to calculate oxygen consumption:

$$\dot{V}O_2 \text{ (liters/min)} = \frac{\Delta P/\text{Hr}}{60 \text{ min/hr}} \cdot \frac{\text{Volume 02 Bottle liters/ATA}}{14.7 \text{ psig/ATA}} \cdot \frac{273°}{273° + 12.8°}$$

$\dot{V}O_2$ = Oxygen consumption (liter/min at STP)

ΔP = Change in oxygen bottle pressure (in psig/hr from graphs)

Volume O_2 Bottles = 2930cc

The gas sample rate was approximately 400 cc/min (at ATP). This resulted in an oxygen loss of either 90 or 110 cc of oxygen per minute for rigs controlling at 0.7 or 0.85 ATA O_2, respectively. Since the volume loss is replaced by air with a $ppO_2$of 0.63 at 3 ATA, 85 cc/minute of oxygen would be made up by the air added from the diluent bottle. Only an additional 5 cc or 25 cc/minute of oxygen would be consumed from the O_2 bottle and included in oxygen consumption for the 0.7/0.85 ppO_2 set point rigs respectively. This consideration would also apply to gas lost from the UBA as a result of leaks; the errors resulting from these losses are thus negligible and may be ignored.

Canister Duration Calculations

Operating limits for canisters using a given set of conditions are calculated by subtracting 1 standard deviation from the mean time to canister breakthrough, which is defined as 0.5% surface equivalent canister effluent CO_2. The time to breakthrough for the work/rest cycle protocols, in turn, is calculated by taking the point at which a computer generated best fit curve to the average (including both working and resting cycles) CO_2 levels seen in the sample crossed the 0.5% SEV line. Breakthrough for the resting cycles was calculated slightly differently and is said to occur when the average CO_2 at rest rises to 0.5% SEV or when the CO_2 during the one work cycle per hour reaches 1.5%.

Resting Schedule

Three trials were completed using the resting exercise schedule. A fourth was aborted because of a canister flood out. The data for these studies is contained in Figures 1-3 and summarized in Table 2. The mean oxygen consumption in the resting scenario was 0.92 liters/minute STP and the calculated canister duration was 565 minutes.

TABLE 2

RESTING SCHEDULE

RIG #	DIVER #	CANISTER WEIGHT (Kg) Pre-Dive	CANISTER WEIGHT (Kg) Post Dive	$\dot{V}O_2$	Minutes to 0.5% SEV	Minutes to 1.0% SEV
1	3/7	5.205	5.948	0.99	720*	---
2	2/10	5.182	6.156	0.84	590	---
3	1/6	5.272	6.218	0.92	600	---
Mean				0.92	637	
Standard Deviation					72	
Canister Duration					565	

* Breakthrough did not occur. Test terminated at 720 minutes.

50 Watt Schedule

Four trials were completed using the 50 watt exercise schedule. The data for these studies is contained in Figures 4 through 7 and is summarized in Table 3. The mean oxygen consumption was 1.28 liters/minute STP and the canister duration for this schedule was 326 minutes. Note that the data from rig #4 was not included in the canister calculations. Several of the divers complained about increased resistance on this ergometer and the oxygen consumption calculated post-dive was 450 cc/min higher than the mean of the other three. The same pattern was noted on the 100 watt exercise schedule below.

100 Watt Schedule

Four trials were completed using a 100 watt exercise schedule. The data from these studies is contained in Figures 8-11 and summarized in Table 4. The mean oxygen consumption was 1.56 liters/minute STP and the canister duration for this exercise rate was 247 minutes. The data from rig #4 was excluded from the canister calculations for the reasons enumerated above.

Oxygen Consumption Versus Canister Duration

Figure 12 is a plot of the oxygen consumption versus canister duration for each individual test conducted. The curved line is the best fit second order polynomial to the individual data points. The straight line is the slope of the linear regression line to this data, but with the Y intercept shifted downward so that all 0.5% breakthrough points lie either on or above the line.

DISCUSSION

Traditionally, canister durations have been measured using a diver working intermittently at 50 watts on a bicycle ergometer. This work rate has been used since it represents an oxygen consumption of approximately 1.5 liters per minute. This is equivalent to a diver swimming at 0.8 knots and represents a comfortable work rate that a well conditioned diver can sustain for a prolonged period of time.

In this study the mean oxygen consumption at 50 watts was 1.28 liters per minute. However, in a previous study conducted by Jaeggers and Thalmann, mean diver oxygen consumption using the EX 15 and the same dry suit at the same water temperature was 1.6 liters per minute[3]. Similar studies conducted by Piantadosi, Clinton, and Thalmann indicate a mean oxygen consumption of 1.5 liters per minute. The lower oxygen consumption in this study probably represents a change in the ergometer calibration procedure instituted for this study which although probably more accurate also results in a decreased ergometer resistance and therefore a reduced oxygen consumption.

TABLE 3

50 WATT SCHEDULE

RIG #	DIVER #	CANISTER WEIGHT (Kg) Pre-Dive	CANISTER WEIGHT (Kg) Post Dive	$\dot{V}O_2$	Minutes to 0.5% SEV	Minutes to 1.0% SEV
1	5	5.139	5.940	1.31	360	---
2	1/2	5.101	5.817	1.28	335	395
3	7/8	5.166	6.155	1.26	330	390
4	3	5.13	5.87	1.73*	245*	290
Mean				1.28	342 min	358
Standard Deviation					16	
Canister Duration					326	

* Not included in canister calculations. Oxygen consumption elevated due to ergometer malfunction.

TABLE 4

100 WATT SCHEDULE

RIG #	DIVER #	CANISTER WEIGHT (Kg) Pre-Dive	Post Dive	$\dot{V}O_2$	Minutes to 0.5% SEV	Minutes to 1.0% SEV
1	4	5.141	-----	1.66	325	370
2	10	5.333	-----	1.51	290	345
3	5/8	5.299	-----	1.52	245	290
4	6/2	5.205	-----	1.90*	210*	240
Mean				1.56	287	
Standard Deviation					40	
Canister Duration					247	

* Not included in canister calculations. Oxygen consumption elevated due to ergometer malfunction.

To obtain a more meaningful oxygen consumption representing a swimming diver, we have chosen to predict canister duration from the oxygen consumption versus canister duration chart, Figure 12. This yielded a canister duration of 280 minutes. Similarly, oxygen consumption for a largely resting diver was taken at 0.9 liters per minute which gives a predicted canister duration of 480 minutes.

These predicted durations were measured from a best fit linear regression line that had been shifted downward so that all times to reaching 0.5% SEV of carbon dioxide lay either on or above this line. This line yields more conservative results than other regression techniques, but also offers the advantage of simplicity in determining canister duration under other conditions where oxygen consumption rates are different.

Such conditions are likely to occur when diving in water colder than the 12°C used in this study. In this instance, shivering thermogenesis may occur increasing a divers' oxygen consumption higher than normal for the work rate. Such a situation will also occur when a diver uses a thermal protection garment less effective than those used in this study. Thus, the above canister duration times for either a swimming or resting diver may not apply under conditions of colder water, or decreased thermal comfort resulting from a less effective thermal protection garment.

However, once approximate oxygen consumptions are known for a variety of underwater activity, using several different thermal protection garment types, appropriate canister durations can be predicted. These canister durations will in most instances be longer than using an approach based only on measured times for a limited range of diver activity such as resting of a sustained swimming rate. Once the oxygen cost of underwater activity in various water temperatures using a variety of thermal protection garments are used, a simple model for determining canister duration based upon oxygen bottle pressure drop can be developed. Such a model will yield maximum flexibility when planning missions under a variety of conditions.

Previous unmanned and manned testing indicates that the performance of the EX 15 Mod 1 canister is independent of temperature. However, unmanned testing suggests that canister duration is significantly reduced at depths greater than 60 FSW using nitrogen oxygen mixtures. A similar reduction in canister duration occurs at depth greater than 100 FSW nitrogen oxygen mixtures. Further, manned and unmanned testing will be required to define actual canister duration degradation for diving at depths greater than 60 and 100 FSW respectively.

CONCLUSIONS

1. The recommended EX 15 Mod 1 canister duration for most diving operations is 280 minutes independent of water temperature.

2. The recommended EX 15 Mod 1 canister duration for divers in a resting scenario, such as riding in an SDV, is 480 minutes independent of water temperature.

3. Canister duration was observed to have an inverse relationship to diver oxygen consumption, with the decrease in canister duration proportional to the increase in oxygen consumption.

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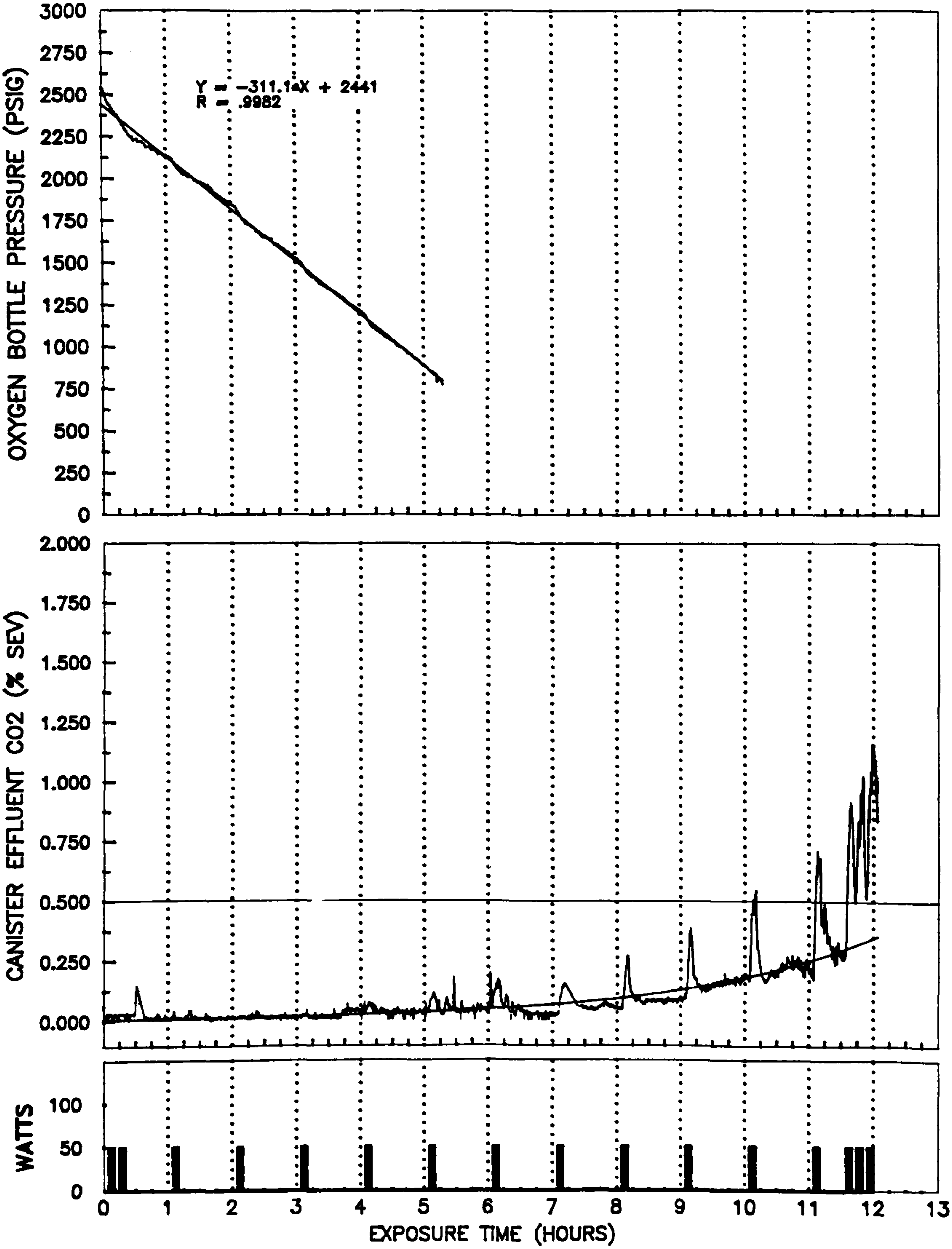


Figure 1. Resting canister study (canister 1). Graphs show oxygen bottle pressure, canister effluent carbon dioxide level, and diver work rate as a function of exposure time in hours.

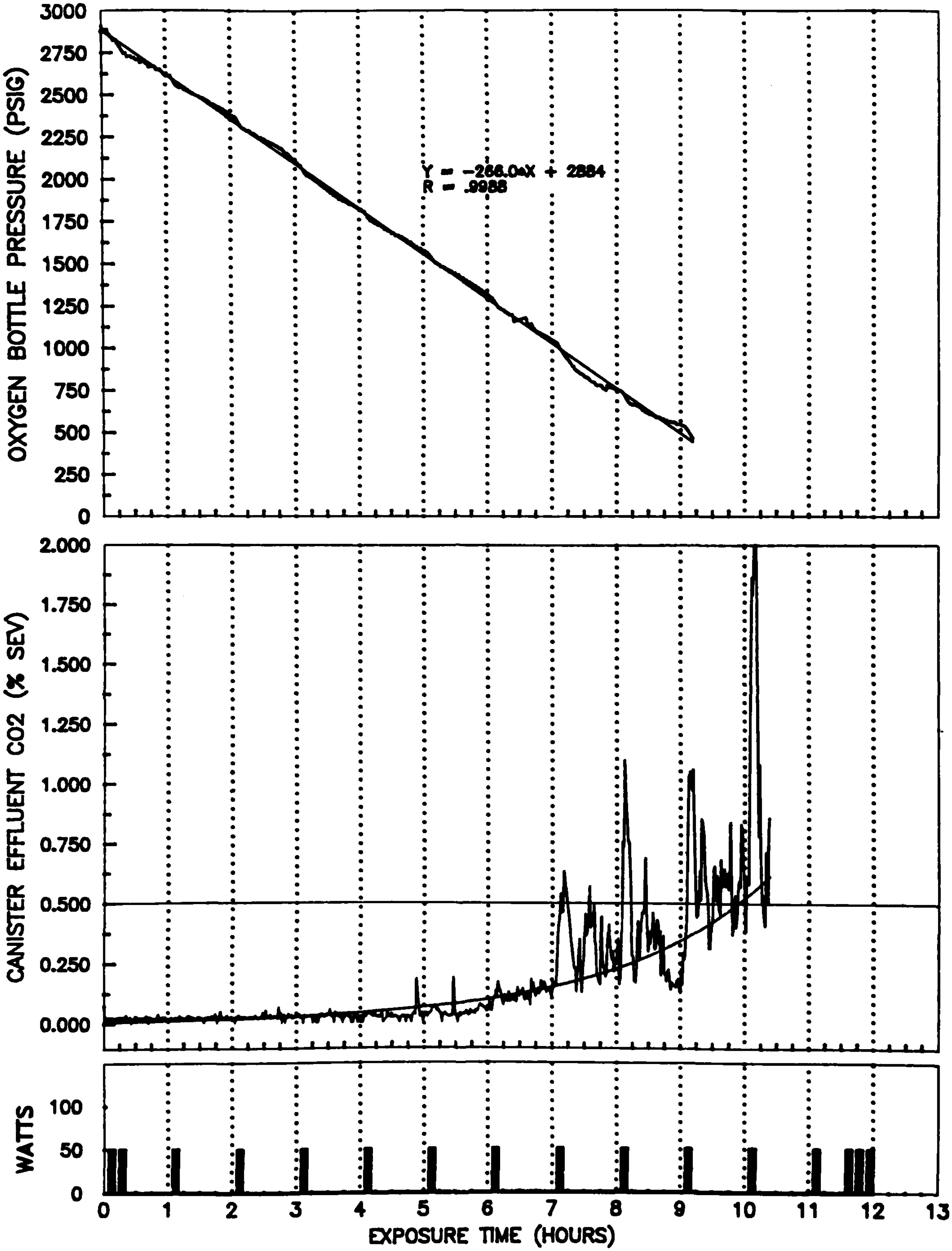


Figure 2. Resting canister study (canister 2). Graphs show oxygen bottle pressure, canister effluent carbon dioxide level, and diver work rate as a function of exposure time in hours.

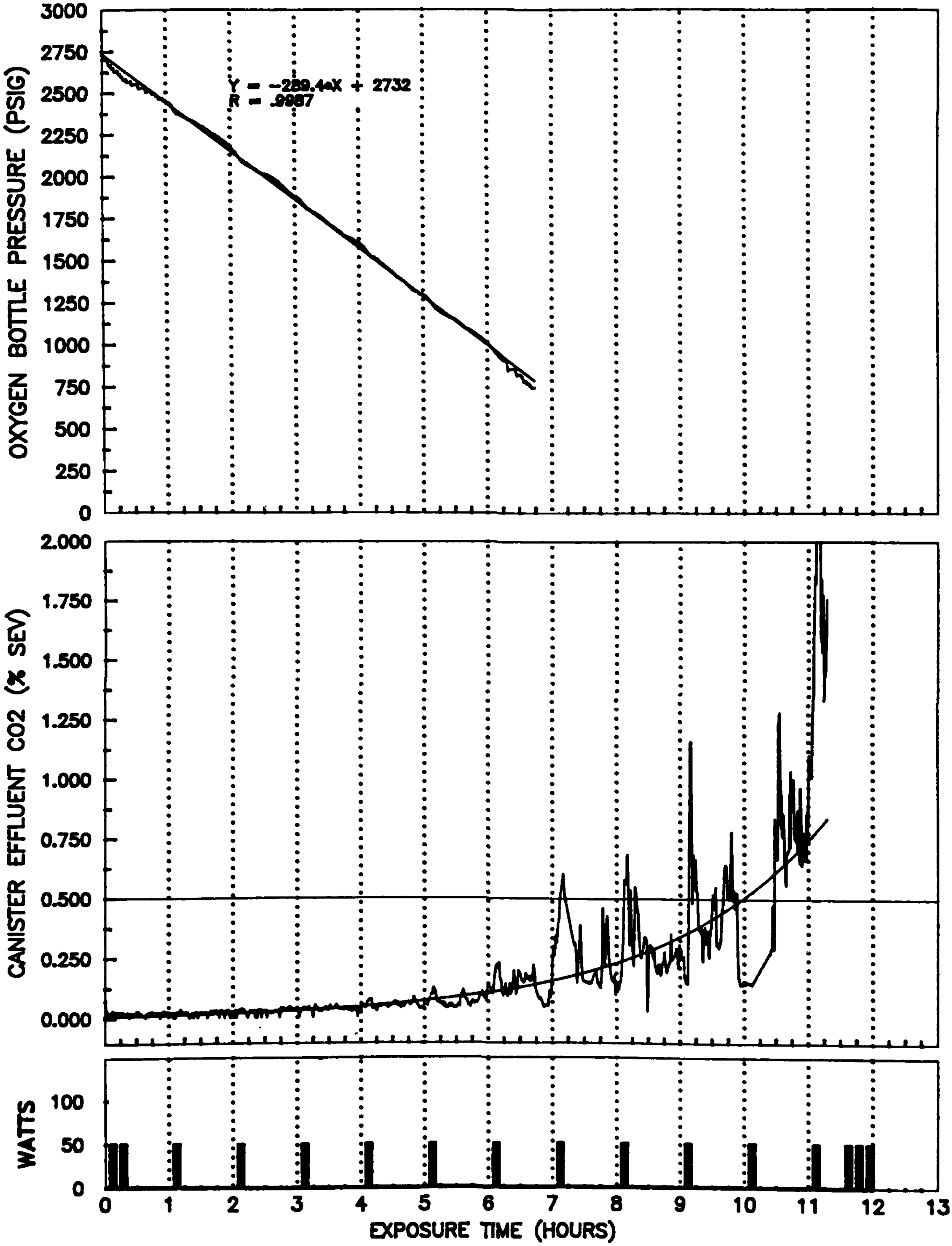


Figure 3. Resting canister study (canister 3). Graphs show oxygen bottle pressure, canister effluent carbon dioxide level, and diver work rate as a function of exposure time in hours.

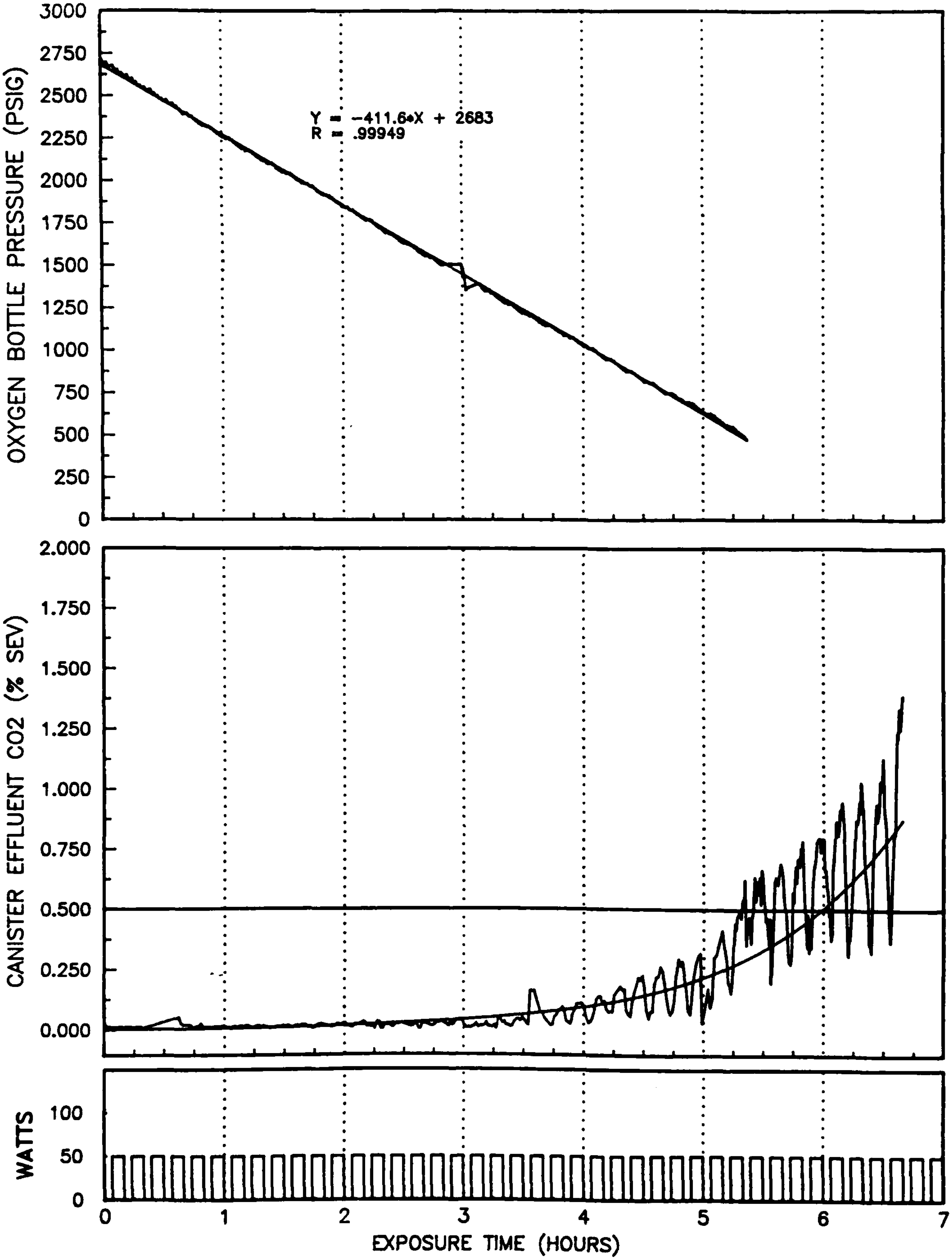


Figure 4. 50 watt canister study (canister 1). Graphs show oxygen bottle pressure, canister effluent carbon dioxide level, and diver work rate as a function of exposure time in hours.

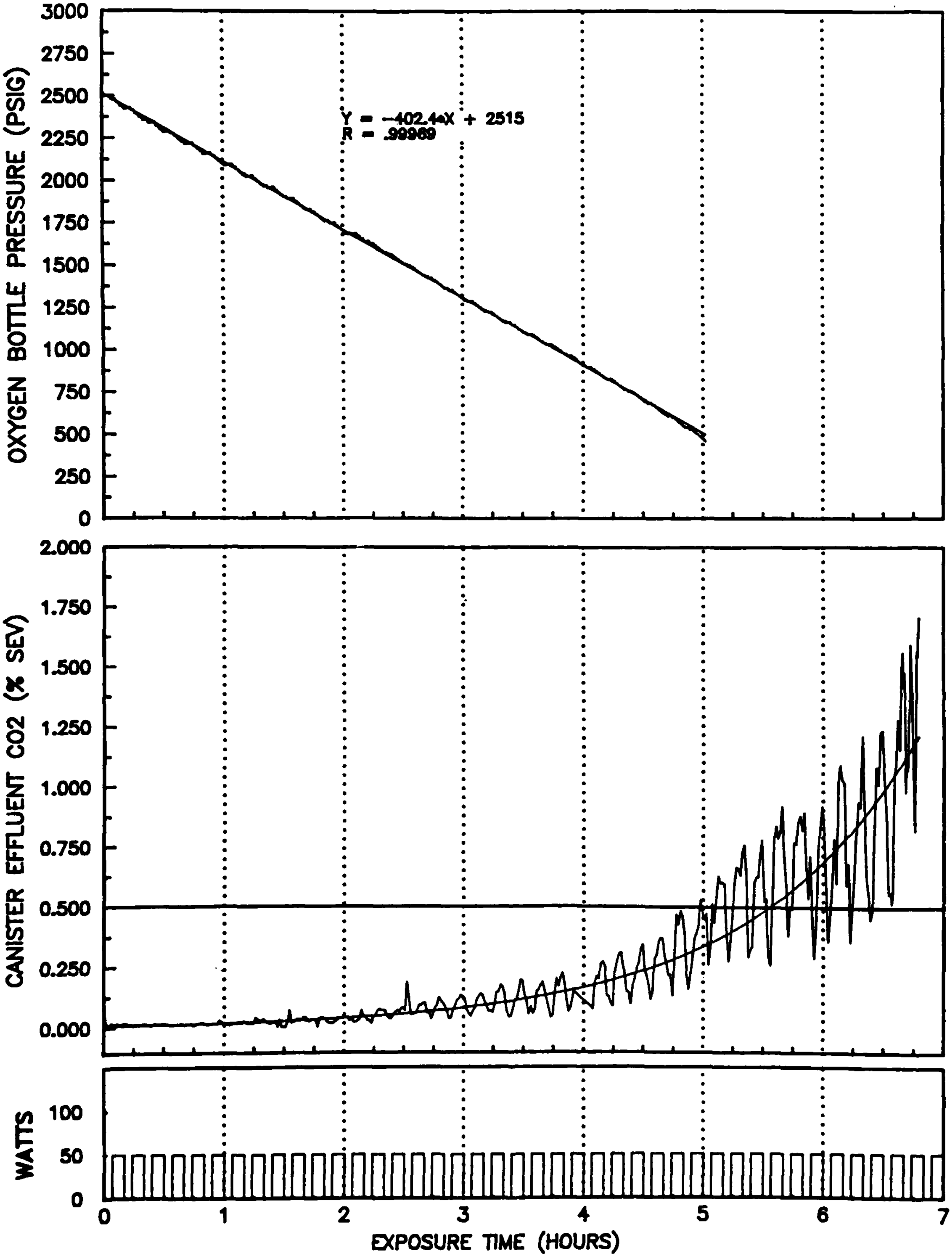


Figure 5. 50 watt canister study (canister 2). Graphs show oxygen bottle pressure, canister effluent carbon dioxide level, and diver work rate as a function of exposure time in hours.

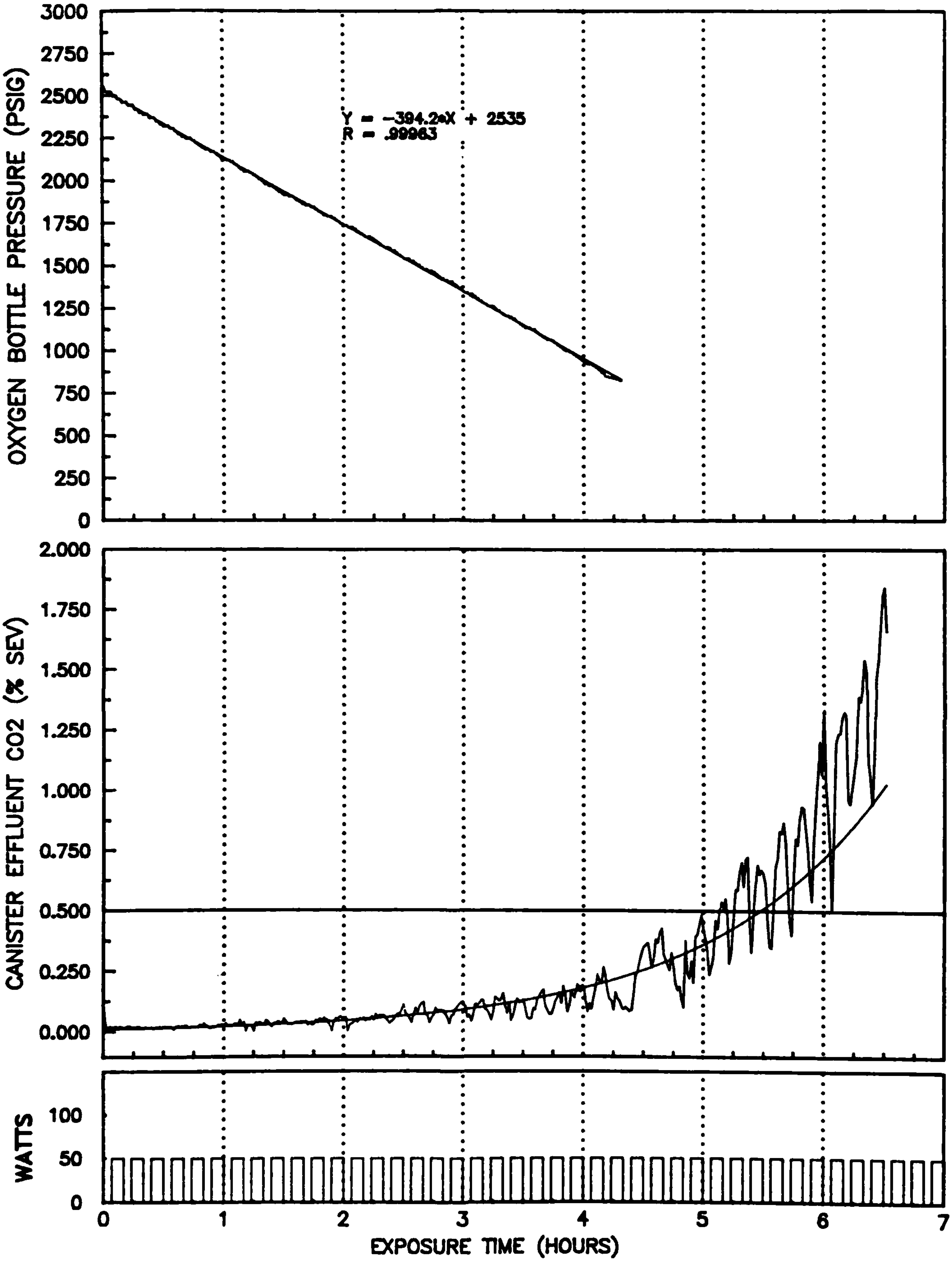


Figure 6. 50 watt canister study (canister 3). Graphs show oxygen bottle pressure, canister effluent carbon dioxide level, and diver work rate as a function of exposure time in hours.

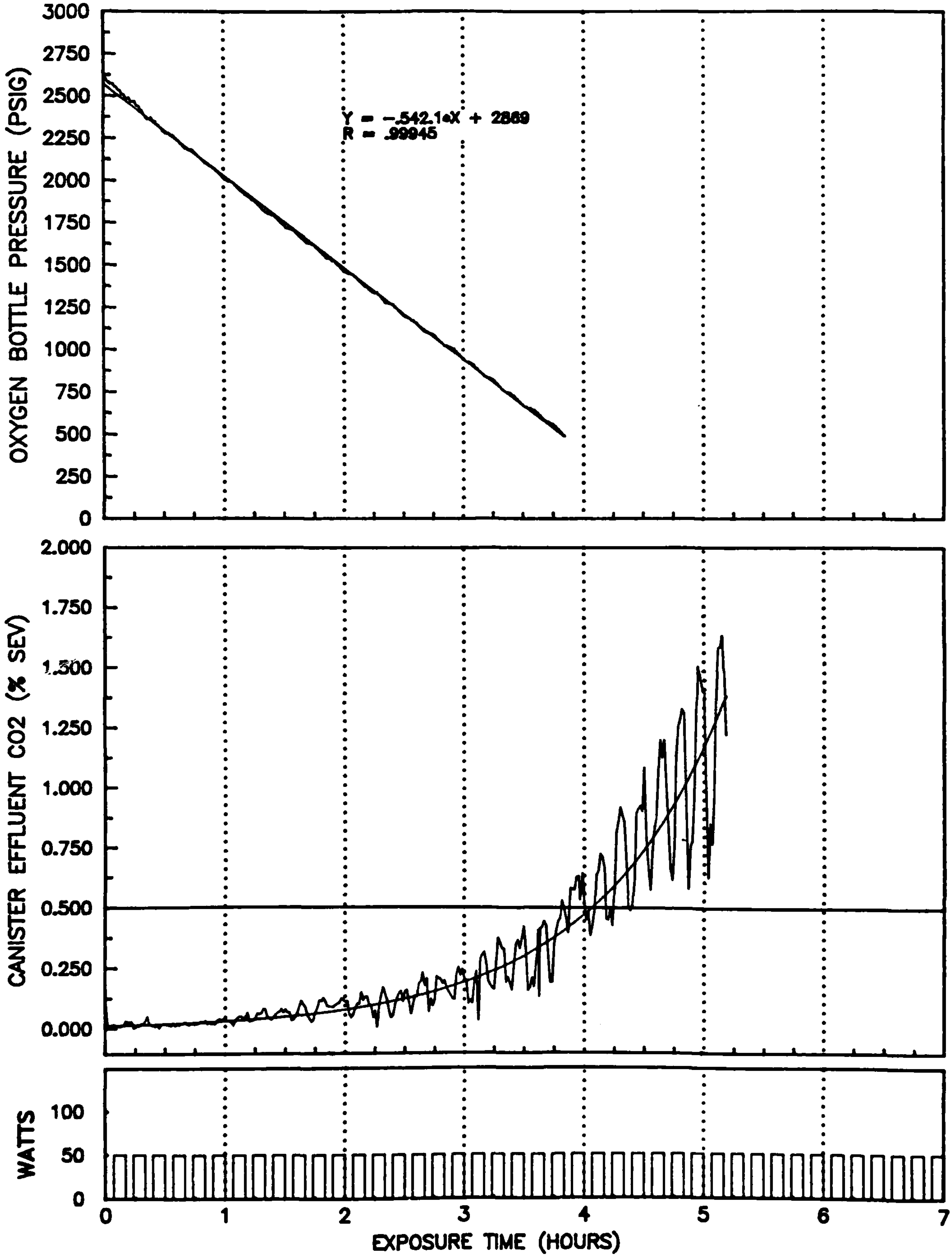


Figure 7. 50 watt canister study (canister 4). Graphs show oxygen bottle pressure, canister effluent carbon dioxide level, and diver work rate as a function of exposure time in hours.

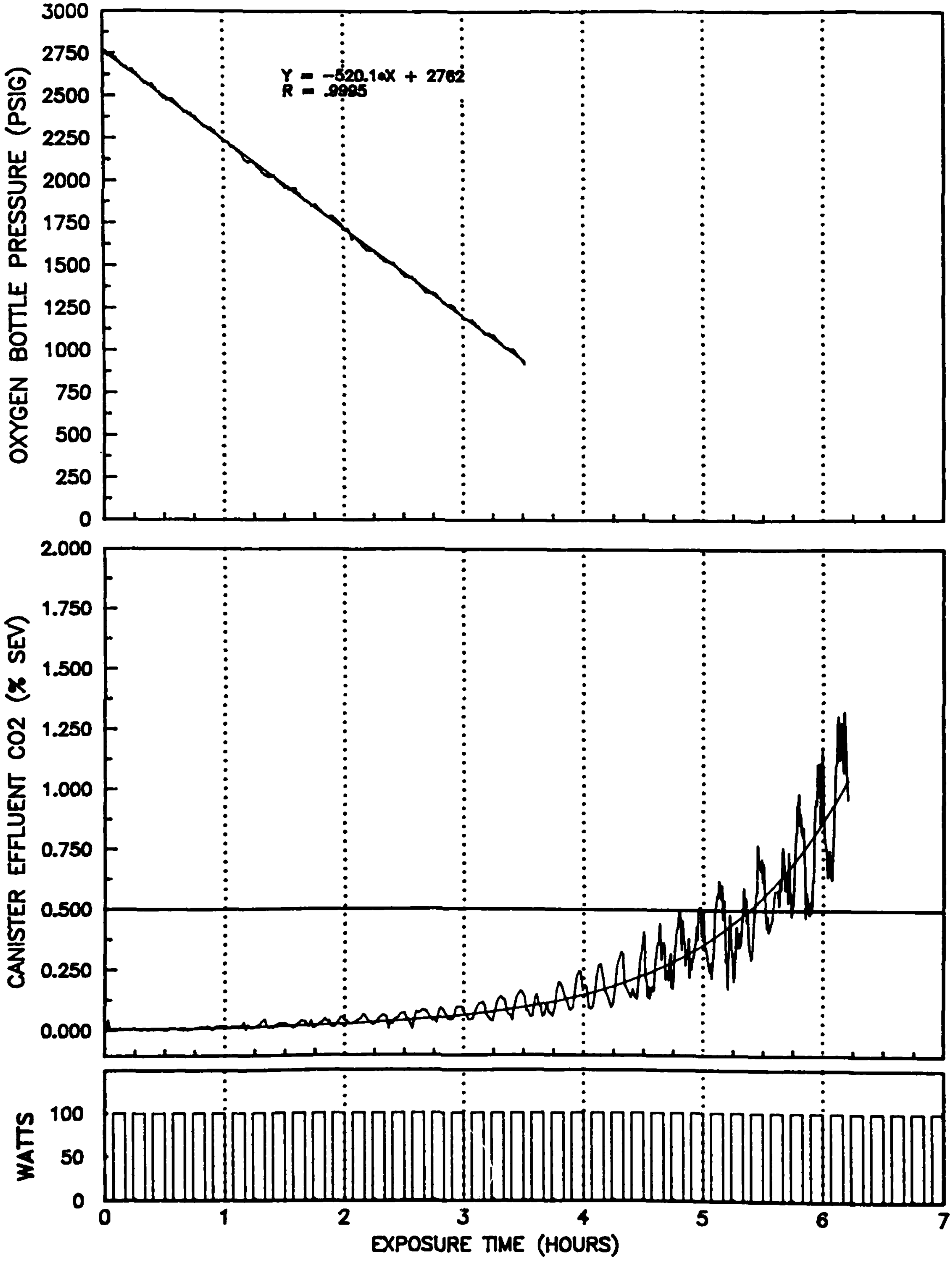


Figure 8. 100 watt canister study (canister 1). Graphs show oxygen bottle pressure, canister effluent carbon dioxide level, and diver work rate as a function of exposure time in hours.

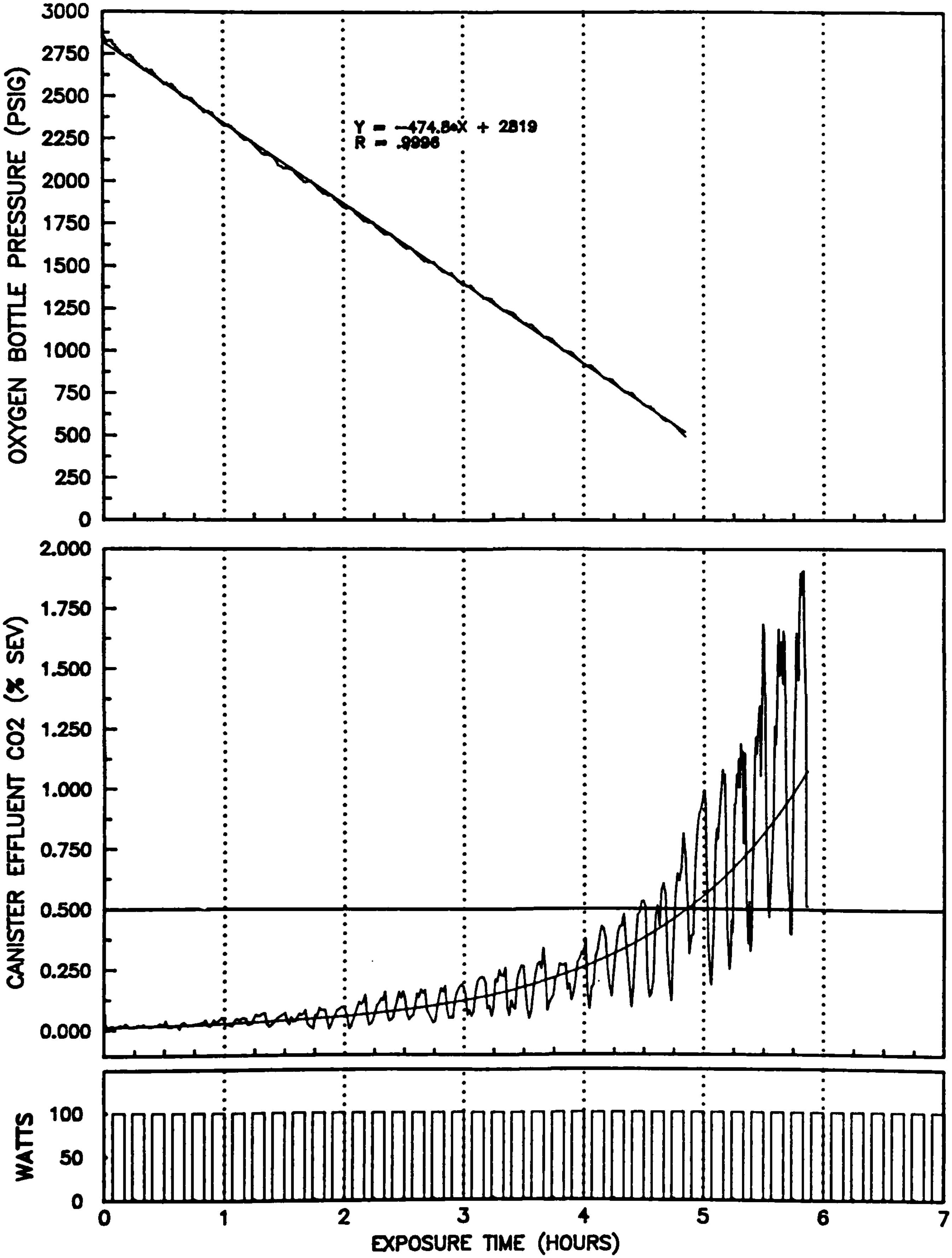


Figure 9. 100 watt canister study (canister 2). Graphs show oxygen bottle pressure, canister effluent carbon dioxide level, and diver work rate as a function of exposure time in hours.

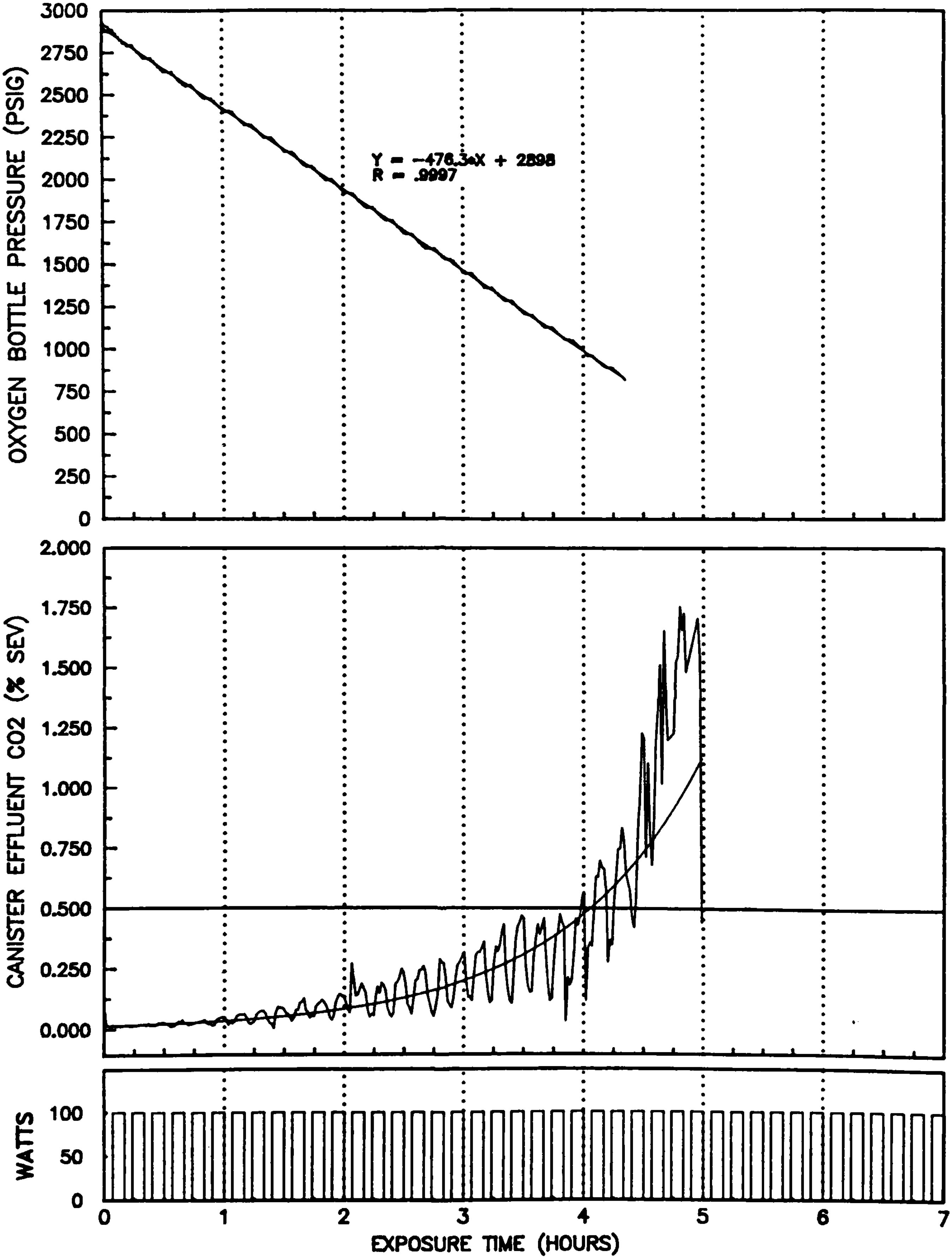


Figure 10. 100 watt canister study (canister 3). Graphs show oxygen bottle pressure, canister effluent carbon dioxide level, and diver work as a function of exposure time in hours.

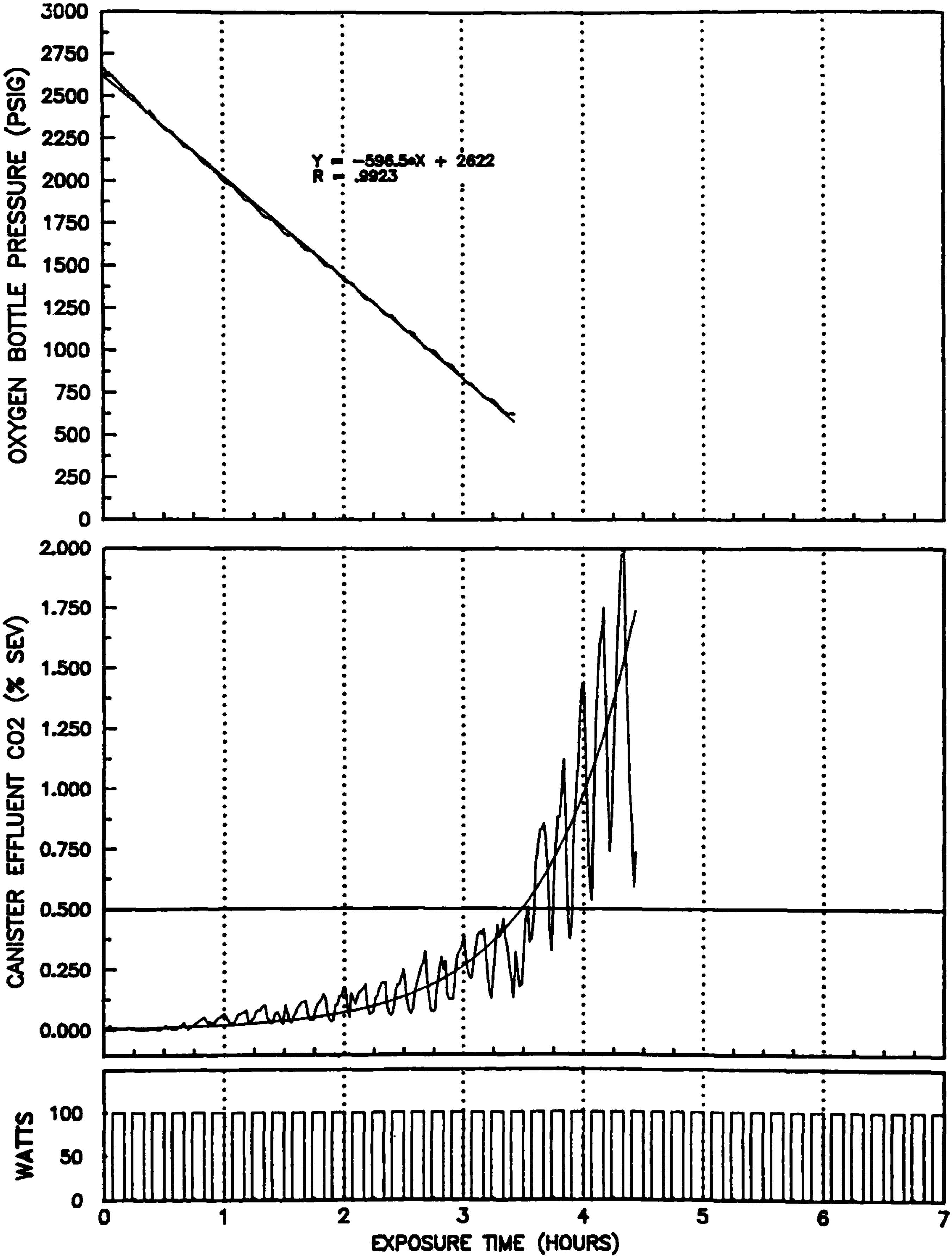
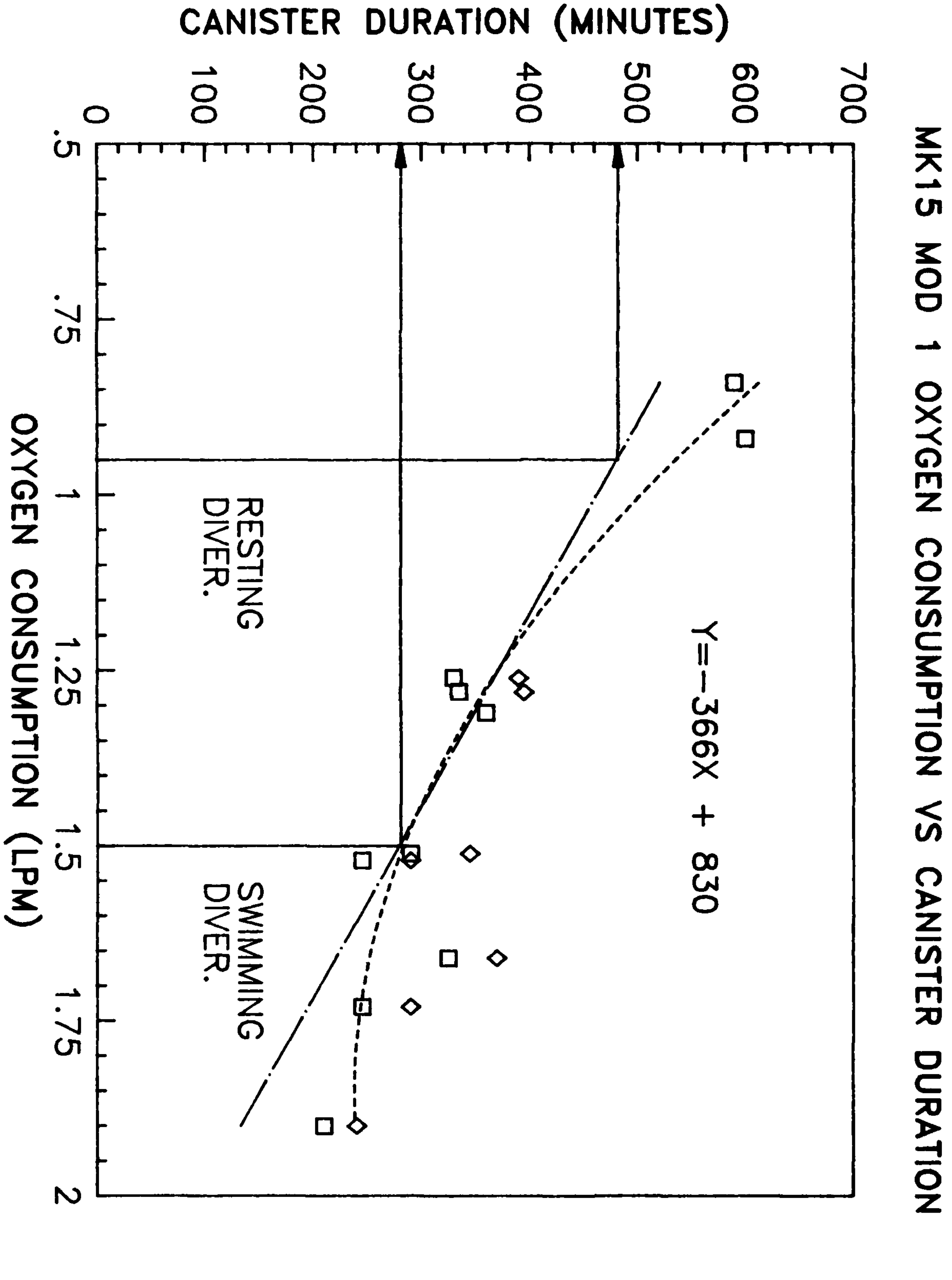


Figure 11. 100 watt canister study (canister 4). Graphs show oxygen bottle pressure, canister effluent carbon dioxide level, and diver work as a function of exposure time in hours.



MK15 MOD 1 OXYGEN CONSUMPTION VS CANISTER DURATION
CANISTER DURATION (MINUTES)
OXYGEN CONSUMPTION (LPM)
Y=-366X + 830
RESTING DIVER.
SWIMMING DIVER.
0
100
200
300
400
500
600
700
.5
.75
1
1.25
1.5
1.75
2

FIGURE 12

END

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